OPEN ACCESS International Journal of Plant Breeding and Genetics

ISSN 1819-3595
DOI: 10.3923/ijpbg.2016.

Research Article
GGE Stability Analysis of Seed Yield in Sunflower Genotypes (*Helianthus annuus* L.) in Western Amhara Region, Ethiopia

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Abstract
A suitable sunflower variety was developed with high yield and stability. A total of eleven sunflower genotypes including the standard and local checks were evaluated at Finoteselam, North Achefer and Ayehu from 2010-2013 cropping season. Randomized Complete Block Design (RCBD) with three replications was used. The results of variance analysis showed the significance of environmental variance compared to the genotype and GE interaction variances. Polygon view of GGE biplot revealed that X^7 (Acc. 208768) was the genotype with the highest seed yield in five out of six environments. The Average Environment Coordinate (AEC) biplot showed that X^7 (Acc. 208768) with the highest mean yield was a highly stable genotype as it was positioned close to the AEC abscissa. The biplot of comparison of the sunflower genotypes with the ideal genotype revealed that X^7 (Acc. 208768) was the closest genotype to the ideal cultivar. Therefore, this genotype seems to be widely adapted across several environments and is released as an open pollinated variety for wider production in Western Amhara and similar agro ecologies.

Key words: Sunflower, graphical analysis, GE interaction, average environment coordinate, genotypes

Received: Accepted: Published:

Citation: Cherinet Alem, Abebe Worku, Molla Mekonnen, Tazebachew Asres, Desalew Fentie, Esmelealem Mihiretu and Jemal Esmael, 2016. GGE stability analysis of seed yield in sunflower genotypes (*Helianthus annuus* L.) in Western Amhara region, Ethiopia. Int. J. Plant Breed. Genet., CC: CC-CC.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Sunflower (*Helianthus annuus* L., 2n = 34) an Asteraceae family plant is native to the temperate North America, which is the centre of diversity for this important edible oil-yielding species. Sunflower (*Helianthus annuus* L.) occupies the fourth position among vegetable oil seeds after soybean, oil palm and canola in the world (De Rodriguez *et al*., 2002; Bukhsh *et al*., 2011). Although, sunflower is generally regarded as a temperate zone crop, it is currently cultivated on approximately 23 million hectares in 40 countries of the world, including some countries in the humid tropical Africa because it is quite rustic and can perform well under varying climatic and soil conditions (Seiler *et al*., 2008; Kaleem *et al*., 2011). The major goal of growing sunflower is for its seed (achene) that contains oil (36-52%) and protein (28-32%) as reported by Rosa *et al*. (2009). The crop has been receiving steady attention by various scientists from diverse disciplines in recent past because sunflower oil is a premium oil with light colour and is widely used in the diets of heart patients because it contains very low cholesterol and high (90%) unsaturated fatty acid concentration (Flagella *et al*., 2002; Qahar *et al*., 2010). With the average of 25 million hectares sown lands around the world, sunflower is one of the main crops for the oil production, following soy, cotton and rapeseed (FAO., 2007). In Ethiopia, sunflower total area covered during the year 2009 was 4,430 ha a with production of 3,869 metric tons, average yield of 0.87 metric tones per hectare (CSA., 2009). In Ethiopia, there are other potential oil seeds such as soybean and sunflower that can easily be produced. Both crops have greater potential (Wijnands *et al*., 2007) in countries such as Ethiopia with humid and warm growing conditions. Their oil can contribute to improve the self-sufficiency of the country in edible oil. By adding sunflower to an existing crop rotation, pest problems such as corn borer or soybean cyst nematode can be reduced. Sunflower is shorter season than most crops, so can be planted later or harvested earlier, helping spread out work load. Sunflowers are efficient at extracting water from the soil profile, especially in sandy loam soils and can often tolerate drier conditions better than other crops. In study of tef and sunflower intercropping in dry areas of Ethiopia, mixed cropping of tef and sunflower increased yields and land productivity and improved the monetary return (Bayu *et al*., 2007). The tef (*Eragrostis tef*) and sunflower (*Helianthus annuus*) have different growth durations, canopy positions and rooting depths, which may give them different spatial and temporal demands for resources. Oil seeds are a mainstay of the rural and national economy of Ethiopia. After coffee, oil seeds are the second largest export earner for the country and already more than 3 million farms are involved in its production. At the moment, substantial quantities of edible oils are being imported, so boosting production for the local market can create extra income and substitute import. Also, oil seed cake is very much needed for animal feed. Unfortunately, sunflower is hardly grown at present. Tests in Uganda have shown great potential. Hence, trials have started in Ethiopia to produce sunflower seed more professionally. Next to the normal sunflower seed the high oleic varieties may offer export possibilities. Imports of sunflower oil are considerable in Ethiopia and this could easily be substituted by domestic production. The yield per hectare of sunflower seed (average of 1.8 t ha^{-1}) is approximately doubles that of currently used oil seeds like noug. So, from a food security point of view, sunflower seed can become very important. Measuring and understanding the genotype by environment interaction (GEI) should be an essential component of variety evaluation. One of the main reasons of growing varieties in multi-locations is to estimate their stability (Freeman, 1973) as selection of superior varieties is mainly based on their yield potential and stable performance over a wide range of environments (Crossa *et al*., 1989). To date, little information is available on sunflower crop and its adaptation pattern, especially under Northwestern Ethiopian conditions. Keeping this in view, the present study was conducted to examine the pattern of genotype by environment interaction (GEI) of yield and yield related traits, to identify the most stable sunflower genotype for wide and/or specific adaptations.

MATERIALS AND METHODS

Eleven sunflower genotypes including the standard and local checks were evaluated at Finoteselam, North Achefer and Ayehu from 2010-2013 main cropping season (Table 1). Randomized Complete Block Design (RCBD) with three replications was used throughout the testing locations. Each experimental plot had four rows of 5 m length and 75×30 cm spacing between rows and plants was used, respectively. No Fertilizer applied for all sites. Planting was carried out from mid to the end of June, 2011 following the farmer's practice. All other recommended agronomic and cultural practices were carried out for all the plots uniformly. Combined analyses of

Table 1: Brief description of experimental sites

Location	Altitude (m a.s.l)	Soil type	Global positions
Finoteselam	1917	Nitosol	10°42' N, 37°16' E
North Achefer	2072	Nitosol	11°36' N, 36°57' E
Ayehu	1900	Nitosol	11°20' N, 37°25' E

variance over locations and years were done using SAS software (version 9.0) and stability analysis was done by using GenStat 13th Edition (SP2).

RESULTS AND DISCUSSION

Combined analysis of variance for seed yield (Table 2) showed highly significant variations among Environments (E), Genotypes (G) and genotype by environment interaction (G×E). Highly significant variations observed for much of the parameters tested among genotypes across all locations, indicating the existence of variability among the tested genotypes (Table 3). Significant variations among locations for days to flower, days to maturity, seed yield and branch per plant and among genotypes for days to flower, days to maturity, plant height, seed yield and thousand seed weight were also reported in linseed by Adugna and Labuschagne (2003). Significant genotype by environment interaction was observed for seed yield. Similarly, significant GEI for seed yield was also reported by Adugna and Labuschagne (2003) and Choferie (2008). It agrees with the finding that yield and agronomic traits are influenced by genotypes, environment factors and the interaction between genotype and environment (Adugna and Labuschagne, 2003; Wakjira *et al*., 2004; Choferie, 2008; Berti *et al*., 2010; Gunasekera *et al*., 2006; Mostafa and Ashmawy, 1998).

GGE stability analysis: Yan (2002) declared that typically E explains the most (up to 80% or higher) of total yield variation and G and GE are usually smaller. A high environmental variance was reported in soybean (Gauch, Jr. and Zobel, 1988), cotton (Baxevanos *et al*., 2008; Kerby *et al*., 1996, 2001) and safflower (Pourdad and Mohammadi, 2008; Mohammadi *et al*., 2008). The first two principle components (PC1 and PC2) obtained by singular value decomposition, together explained 92.66% of the total variability caused by GE interaction (Fig. 1). Therefore, most of the information could be graphically displayed in the PC1 vs. PC2 biplot. Yan and Tinker (2005) suggested that the poor explanation of variability by the first two principle components showed the complexity of GE interaction.

The most responsive genotypes were X^8, X^7, X^{11} and X^9 (Fig. 1). By connecting the markers of these corner genotypes a polygon was formed and by drawing perpendiculars to each side of the polygon passing through the origin, the environments were divided among several sectors, each with different corner genotypes (Yan, 2002). The polygon view of the GGE biplot showed that all test environments were divided into two groups. The first group was $+^3$ environments in X^8 sector. In 2nd group other five environments were in X^7 sector. Genotype X^7 had the highest seed yield in X^1, X^2, X^4, X^5 and X^6 environments. This genotype as a vertex cultivar was the one furthest away from the biplot origin, which is an indicator of its responsiveness to environments. The X^7 had the highest mean yield (2926 kg ha^{-1}) among all genotypes (Table 2). Genotypes located near the origin were not responsive to environments and would rank the same in all environments. No environments belonged

Table 2: ANOVA table for seed yield of 11 sunflower genotypes tested at six environments

E+G+GE (%)	Source of variation (SOV)	df	Mean square	Pr>F
11.92	Genotype (G)	10	4874970**	<0.0001
86.36	Location (E)	5	35300534**	<0.0001
	Rep with in location	2	164861	0.3123
1.7	Genotype×Environment (G×E)	50	697986**	<0.0001
	Pooled error	100	140022	
	R-square		0.94	

**df: Degree of freedom

Table 3: Mean grain yield, oil content and other agronomic parameters of 11 sunflower genotypes combined over locations and years at F/Selam, Ayehu and N/Achefer

Treatments	DF	DM	PH	NBPP	NHPP	TSW (g)	OC (%)	GY (kg ha^{-1})	OY (kg ha^{-1})
Acc. 202497	89	129	158	7 (2.3)	3.2 (1.8)	62	30.13	1881	567
Acc. 208461	107	143	200	10 (3.2)	9.8 (3.1)	62	32.16	2116	681
Acc. 212995	97	141	181	10 (3.1)	7.1 (2.6)	66	33.50	2335	782
Acc. 2313891	90	137	152	9 (2.7)	6.8 (2.4)	58	30.03	1919	576
Acc. 202496	88	128	148	4 (1.7)	1.7 (1.4)	62	29.40	1696	499
Acc. 202490	91	129	149	6 (2.2)	4.2 (1.9)	53	28.18	1668	470
Acc. 208768	106	139	207	4 (1.9)	3.9 (1.9)	68	32.74	2926	958
Acc. 231380	95	139	157	8 (2.5)	4.6 (1.9)	61	32.98	2211	729
Acc. 231374	87	126	126	4 (1.7)	1.5 (1.4)	47	32.31	951	307
Oissa/NHS-25 (St. check)	98	142	188	7 (2.3)	3.5 (1.7)	61	33.80	2556	864
Local check	114	161	227	4 (1.8)	2.7 (1.7)	71	31.91	2273	725
Mean	96	138	172	2.31	1.97	61	31.56	2048	
LSD (0.05)	2.8	3.7	13.6	0.5	0.41	4.95	2.12	248	
CV	4.3	4	12	30	32	12	7.2	18	

DF: Days to flower, DM: Days to maturity, PH: Plant height, NBPP: No. of branch per plant, NHPP: No. of head per plant, TSW: Thousand seed weight, OC: Oil content, GY: Grain yield, OY: Oil yield, LSD: Least significant difference and CV: Coefficient of variation

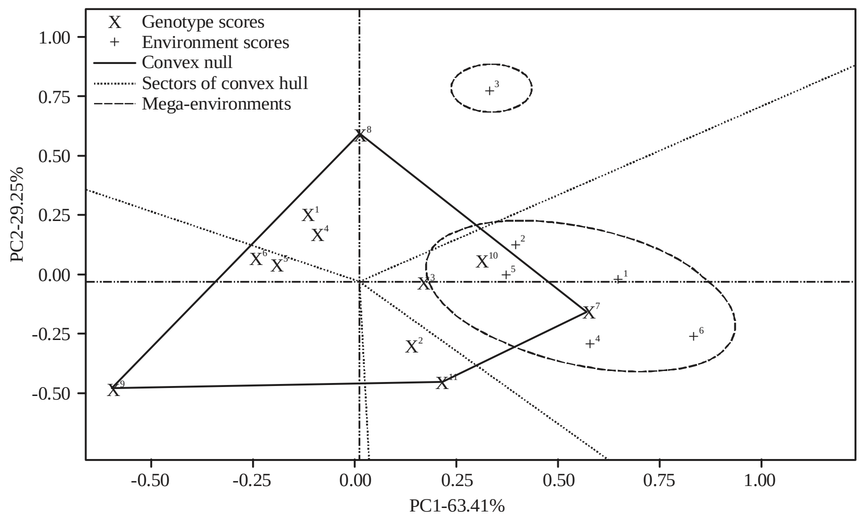

Fig. 1: Polygon view of GGE biplot for the 'Which-Won-Where' pattern, X^1: Acc. 202497, X^2: Acc. 208461, X^3: Acc. 212995, X^4: Acc. 2313891, X^5: Acc. 202496, X^6: Acc. 202490, X^7: Acc. 208768, X^8: Acc. 231380, X^9: Acc. 231374, X^{10}: Oissa/NHS-25, X^{11}: Local check, $+^1$: North Achefer 2011, $+^2$: Finoteselam 2011, $+^3$: Finoteselam 2010, $+^4$: Ayehu 2012, $+^5$: Finoteselam 2012, $+^6$: North Achefer 2012

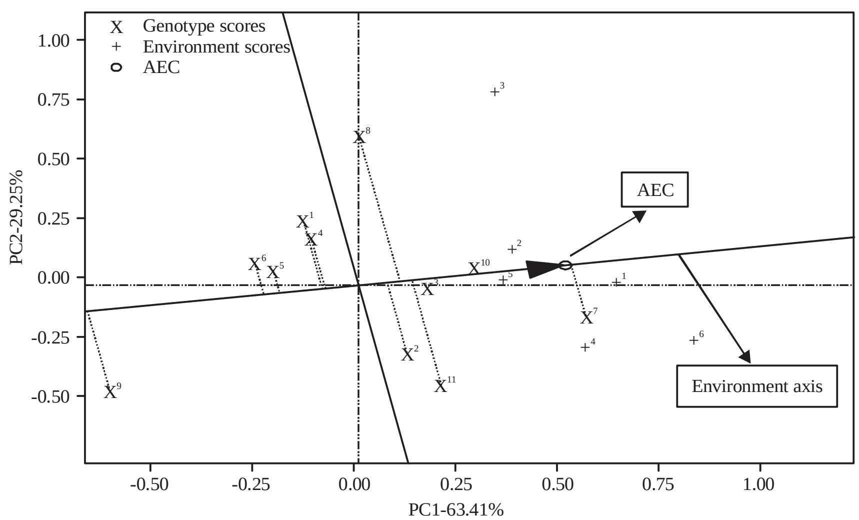

Fig. 2: Average environment coordinate biplot to select yield and stability simultaneously in sunflower genotypes, X^1: Acc. 202497, X^2: Acc. 208461, X^3: Acc. 212995, X^4: Acc. 2313891, X^5: Acc. 202496, X^6: Acc. 202490, X^7: Acc. 208768, X^8: Acc. 231380, X^9: Acc. 231374, X^{10}: Oissa/NHS-25, X^{11}: Local check, $+^1$: North Achefer 2011, $+^2$: Finoteselam 2011, $+^3$: Finoteselam 2010, $+^4$: Ayehu 2012, $+^5$: Finoteselam 2012, $+^6$: North Achefer 2012 and AEC: Average environment coordinate

to the same sectors as X^9, as the vertex genotype. This indicated that this genotype was the poorest in some or all environments.

To consider the yield and stability simultaneously the Average Environment Coordinate (AEC) biplot was used (Fig. 2). It showed the ranking of 11 genotypes in terms of their mean yield and stability. The average environment, represented by a small circle is defined by the PC1 and PC2 scores of the environments. The line passing through the biplot origin and average environment is called the average environment axis and serves as the abscissa of the AEC. Projections of genotypes onto this axis show the approximate mean yield of the genotypes. The ordinate of the AEC is the line that passes through the origin and is perpendicular to the AEC abscissa. Unlike the AEC abscissa, which has one direction, with the arrow pointing to the greater genotype mean effect, the AEC ordinate is indicated by double arrows, either direction away from the biplot origin indicates a greater GE

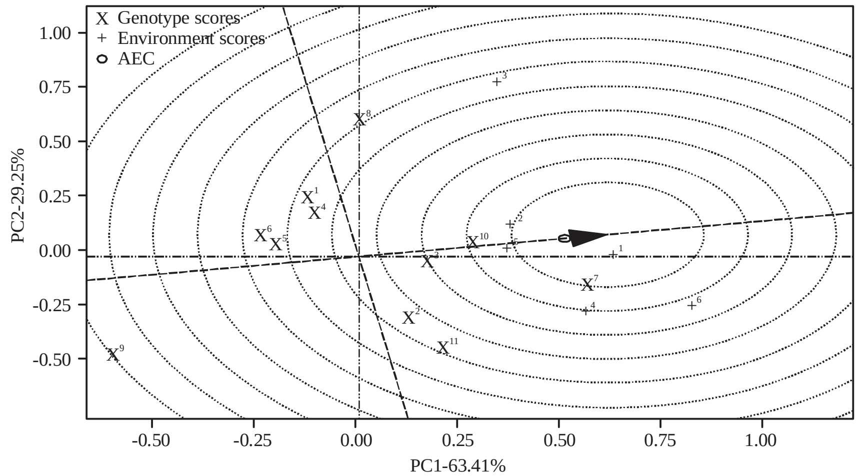

Fig. 3: Biplot of comparison of the sunflower genotypes with the genotype ideal for yield and stability, X^1: Acc. 202497, X^2: Acc. 208461, X^3: Acc. 212995, X^4: Acc. 2313891, X^5: Acc. 202496, X^6: Acc. 202490, X^7: Acc. 208768, X^8: Acc.231380, X^9: Acc.231374, X^{10}: Oissa/NHS-25, X^{11}: Local check, $+^1$: North Achefer 2011, $+^2$: Finoteselam 2011, $+^3$: Finoteselam 2010, $+^4$: Ayehu 2012, $+^5$: Finoteselam 2012, $+^6$: North Achefer 2012 and AEC: Average environment coordinate

effect and reduced stability (Yan, 2002). The genotype X^7 was the top yielding genotype, as presented on the front of an average environment towards the pointing arrow of the AEC abscissa. In addition, the biplot indicated that X^7 with the highest mean yield was highly stable, as it is positioned close to the AEC abscissa (Fig. 2). The second and third highest yielding and most stable genotype was X^{10} and X^3, respectively. In contrast, X^8 was the most unstable genotype, as it was away from the AEC abscissa. An ideal genotype is defined as one that is the highest yielding across all test environments and is absolutely stable in performance, namely one that ranks the highest in all test environments (Yan and Kang, 2003). Although such an ideal cultivar may not exist in reality, it can be used as a reference for cultivar evaluation. A genotype is more desirable if it is located closer to the ideal cultivar. Thus, using the ideal cultivar as the center, concentric circles were drawn to help visualize the distance between each genotype and the ideal cultivar (Yan, 2002).

Figure 3 showed that X^7 was the closest genotype to the ideal cultivar, therefore seems to be widely adapted across several environments. This genotype was followed by X^{10} but X^9 was the furthest genotype from the ideal cultivar. It is interesting to note that the genotype rankings in Fig. 2, based on mean performance and genotype rankings in Fig. 3, based on both mean performance and stability, are almost identical. This is due to the G being greater than GE (Table 1).

CONCLUSION

The combined ANOVA for grain yield revealed highly significant ($p<0.01$) for genotypes, environments and their interactions. Genotype X^7 (Acc. 208768) had 12.65% and 22.32% seed yield advantage and 9.8 and 24.32% oil yield advantage over the standard and local check, respectively. According to GGE stability analysis, genotype X^7 (Acc. 208768) seems to be widely adapted across several environments and is released as an open pollinated variety for wider production in Western Amhara region and similar agro ecologies.

ACKNOWLEDGMENTS

This study was part of a Regional Sunflower Research Project of Adet Agricultural Research Center (AARC) under Amhara Region Agricultural Research Institute (ARARI) of Ethiopia. Special thanks go to Adet Agricultural Research Center (AARC) and Public Private Partnership Project from Netherland Embassy (PPPO) for the financial assistance and resources. We thank all members of the project for any contribution they may have made towards this study.

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